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MORTALITY, CLIMATE AND AIR POLLUTION CAUSE NITROGEN IMBALANCE IN A TOLERANT HARDWOOD FOREST SOIL

by

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INTRODUCTION

To assure healthy and productive forests for future generations, foresters should understand how nutrient demand and supply balance in forested ecosystems and how management interventions affect this balance. Forest harvesting (Fig. 1) increases losses by removing organic matter that is integral to nutrient supply and retention on a site (Morrison 1980). Further, forest floor decomposition after harvesting may increase leaching of newly released nutrients. Long-term exposure of forests to airborne pollutants, also a concern to foresters (Anon. 1986), may contribute to the loss of nutrients.

Forestry Canada, Ontario Region (FCOR) scientists have examined nitrogen (N) cycling in a tolerant hardwood forest ecosystem from 1981 to the present. Although their studies did not directly examine the impacts of harvesting, the results explain how the N cycle responds to disturbance.

NITROGEN DYNAMICS IN VEGETATION AND SOIL

Every growing season, trees obtain inorganic N in the form of ammonium (NH_4^+) and nitrate (NO_3^-) ions from the soil solution. Organisms in the forest floor depend on a regular supply of organic N from litterfall. A sensitive N balance between soil inputs and outputs thereby develops in an ecosystem (Fig. 2).

Figure 1. Logging increases nutrient loss from forest sites.

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Trees use N to form proteins. In forests, N is present in foliage, woody parts, annual litterfall and soil. Biological activity, soil temperature, and water movement control the production and circulation of N through the ecosystem.

Ammonification and *aminization* are the processes by which organic N, unavailable to the plant, is converted into NH_4^+. *Nitrification* yields NO_3^- ions. Together, these processes are referred to as *mineralization*. Trees take up N through their roots in the form of NH_4^+ and NO_3^- and return some of this to the forest floor with the annual litterfall. A byproduct of nitrification is the release of hydrogen ions (H^+), which acidify the soil. *Leaching* occurs when such positively charged ions displace other already-adsorbed cations (e.g., calcium, Ca^{2+}), which move downward through the soil in company with negatively charged ions (e.g., NO_3^-) .

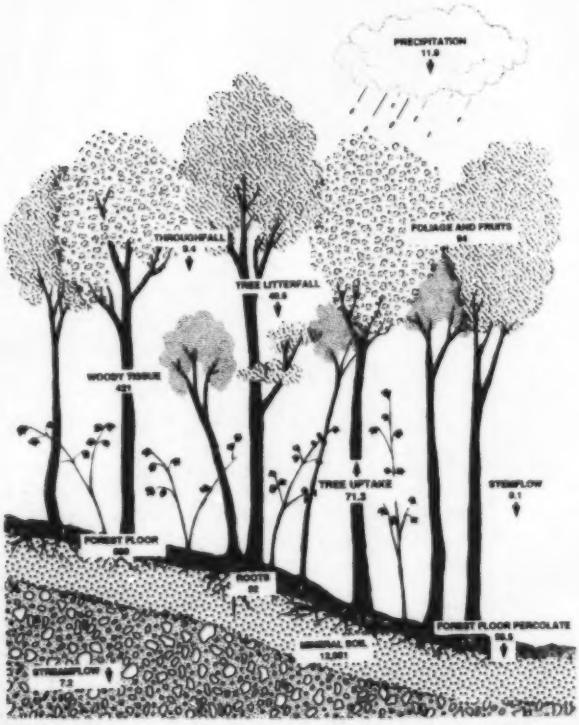

Figure 2. Distribution and annual cycling of N (kg/ha) in a 135- year-old sugar maple-yellow birch forest at the Turkey Lakes Watershed. (Data from Morrison 1990 and Mahendrappa et al. 1986).

THE RESEARCH APPROACH

The 1.0-ha study site was located in the Turkey Lakes Watershed (TLW), 60 km north of Sault Ste. Marie, Ontario. The stand was dominated by uneven-aged sugar maple (*Acer saccharum* Marsh.) with a lesser component of yellow birch (*Betula alleghaniensis* Britton). The dominant maples averaged 135 years old (with some trees twice that age) and stand basal area and gross total volume were 28.6 m^2/ha and 238 m^3/ha, respectively. Growth and the distribution of minerals and organic matter were assessed between 1981 and 1985 (Morrison 1990). Between 1981 and 1986, water was collected below the following levels in the ecosystem: forest canopy, forest floor, and mineral soil at 10 and 60 cm. Streamflow samples were collected from weirs. Litterfall was collected and analyzed monthly (Morrison 1991). Total N uptake was calculated and proportioned among soil horizons according to the relative distribution of fine roots and differences in the mineralization potentials of the horizons. Solution chemistry was summarized seasonally and annually.

FACTORS AFFECTING NITROGEN BALANCE

Natural Disturbance

Table 1 shows that the NO_3^- concentration in soil solution at 60-cm depth in 1986 was nearly twice that in previous years. This probably resulted from a combination of tree mortality and unusually high water movement through the Bhf horizon—143 mm in July and August 1986. Water-balance calculations indicated that there was no water movement through the Bhf horizon in July and August of 1983 and 1985, and that water movement was limited to 22 mm for the same months in 1984 (Foster et al. 1989).

Table 1. Annual variation in mean NO_3^- concentrations in soil solutions from the mature maple-dominated forest at the Turkey Lakes Watershed (from Foster et al. 1989).

Year	Nitrate concentration at 60 cm (μeq/L)	
	Mean	Standard deviation
1983	124	34
1984	135	46
1985	168	36
1986	306	215

Periodic mortality was 0.1 to 3.0 m^2/ha across the watershed as a whole, but 9.5 m^2/ha for the 0.05-ha area in which solutions were collected. It is hypothesized that with the loss of large trees, N uptake and the supply of organic N to the forest floor via litterfall decreased. Ammonium then accumulated in organic layers, where it was subsequently converted to NO_3^-. Rates of mineralization and nitrification in the soil exceeded rates of N uptake by the reduced tree cover. Thus, as water percolated through the soil it was enriched by the increased abundance of nitrate ions.

Site Characteristics

The very large amount of N (>13,000 kg/ha) makes the TLW site more prone to mineralization and leaching than other forest ecosystems in Ontario. Furthermore, the ratio of carbon (C) to N in the litter layer is relatively low (ranging

from 15:1 to 20:1). Because microorganisms depend on N for metabolism, a low C:N ratio favors decomposition of litter and release of inorganic N.

Climatic Effects

Foster (1989) found that leaching of N from the forest floor was greatest during growing seasons with high mean temperature and moisture content. Under these conditions, nitrification and water movement are high. The TLW receives above-average precipitation for Ontario, contributing to high rates of mineralization and leaching.

During warm, dry growing seasons, tree growth slowed and less N moved from the soil to the vegetation. Excess N did not accumulate in the soil; reductions in soil water reduced mineralization, nitrification and N leaching (Foster et al. 1992). The net effect of summer droughts is to conserve soil N.

"N-saturation"

The old-growth study stand has attained an "N-saturated" condition: mineralization exceeds the rates of N uptake by vegetation and of conversion of inorganic N into organic N by soil microbes. Consequently, excess NO_3^- ions are leached from the rooting zone. The forest received less N in precipitation each year than was leached from the effective rooting zone of trees.

Atmospheric Deposition

Deposition of atmospheric NH_4^+ and NO_3^- contributed to N-saturation. Increased deposition, coupled with mortality in old-growth stands, could accelerate the rate at which such sugar maple forests reach this state. Resultant increases in leaching and soil acidity could lead to nutrient deficiencies that cause reduced tree growth on soils low in exchangeable cations such as Ca^{2+} or magnesium (Mg^{2+}).

In parts of Europe, N deposition is extreme. For example, in the southeastern Netherlands, N deposition (as ammonia emitted by stockbreeding farms or evaporated from animal slurry) ranges from 50 to 200 kg/ha/yr in forested areas. In northern Ontario, deposition of N in precipitation ranges from 5 to 15 kg/ha/yr. The Dutch forest has shown decreased vitality over 141,000 ha and yellowing of Scots pine (*Pinus sylvestris* L.) plantations, largely because of high levels of N deposition and resultant N overloads in leaf tissue (van Dijk and Roelofs 1988).

RESTORING NITROGEN BALANCE BY REVEGETATION

At the TLW, stand openings created by tree mortality will likely be filled by saplings and eventually pole-sized trees, with a corresponding increase in N uptake. As a result, NO_3^- leaching will likely diminish. Restoring N uptake, nutrient storage, litterfall and decomposition will move the N cycle back towards balance.

Resilience is an ecosystem's ability to return to a reference state once displaced (Webster et al. 1975). Resilience is important for the long-term response of an ecosystem to nutrient losses caused by a disturbance such as clearcutting (Vitousek et al. 1982). To maintain long-term site productivity, rotation periods should reflect the time needed to replenish stores of nutrients (Likens et al. 1970). Nitrogen, Ca^{2+} and Mg^{2+} are supplied to soil through decomposition of organic matter. Mineral weathering only gradually supplies soils with Ca and Mg. Foresters should be aware that soils vary in their ability to replenish lost nutrients and that the demand for nutrients is greater in continuously exploited forest than in undisturbed forest (Rennie 1955).

CONCLUSIONS

1. Mortality in an old-growth sugar maple stand contributed to decreased N uptake and increased N leaching through the rooting zone.

2. Above-average precipitation during the growing season accelerated the leaching of N from the soil. High forest-floor temperatures increased N mineralization. Drought conditions retarded tree growth, mineralization, nitrification and N leaching.

3. Although "N-saturation" was attained largely through natural processes, atmospheric additions of NH_4^+ and NO_3^- also contributed to this forest condition.

4. Increased mobilization and leaching of N contributed to increased leaching of Ca^{2+} and acidification of the rooting zone.

5. Forest regrowth will restore balance to N circulation. If a large proportion of a site's organic matter is lost through a disturbance, it will take longer to replenish the organic N reserves that help make an ecosystem resilient to nutrient losses. Therefore, nutrients in slash and forest-floor layers should be conserved.

6. Higher levels of atmospheric NO_3^-, combined with a forest disturbance that reduces plant uptake, could lead to damaging nutrient losses on mature hardwood sites with poor capacities to withstand increases in leaching and acidity.

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